Larval Host-Plant Testing of *Tinostoma smaragditis* (Lepidoptera: Sphingidae), the Fabulous Green Sphinx of Kaua'i

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ABSTRACT. A specimen of an extremely rare sphingid, *Tinostoma smaragditis*, endemic to the island of Kaua'i, Hawai'i, was collected in late July 1992. Prior to expiring, it oviposited 56 eggs, of which 79% were fertile and eclosed, providing a brief opportunity to discover its unknown, larval host-plant(s). Almost 140 species of plants, many endemic to the Hawaiian Islands, were offered to the larvae through a combination of 3 methods. Among the plants was the species upon which the adult was found as well as suspected host plant species. Larvae did not respond to any plant species tested; larvae attempting to feed or actually feeding were not observed. Thus the host-plant(s) remains unknown. Names of plant species offered to the larvae are provided and are considered unlikely host-plants given the lack of immature response.

INTRODUCTION

Tinostoma smaragditis Meyrick (Lepidoptera: Sphingidae) is known as the fabulous green sphinx of Kaua'i or elusive green sphinx of Kaua'i (Zimmerman 1958). It is considered endemic to Kaua'i (Nishida 1992), though Zimmerman (1958) questioned its status as a native. The type specimen was collected in the 1890s and is part of the collection of The Natural History Museum, London (formerly British Museum (Natural History)) (Zimmerman 1958). It was not until July 1961 that a second specimen was collected (Bryan 1962). By 1984, 15 adult specimens were known to exist (Bianchi 1986). With the addition of the adult specimen mentioned in this paper, the total number of adult specimens recorded is 16.

Zimmerman (1958) characterized this species succinctly as "an enigma." According to Bianchi (1986), *T. smaragditis* eggs, large larvae, and pupae are unknown. Riotte (in litt., 1993) indicated that first instars would feed on an artificial diet composed largely of soaked pinto beans, brewers yeast, and agar. However, larvae reaching second instar drowned in water from the medium. He made no attempt to feed larvae plant material. This was probably because the host plant was unknown (Zimmerman 1958), even though August Kusche claimed in 1920 (according to Zimmerman 1958) that he had found the larvae on *Lysimachia hillebrandi* J.D. Hook. ex A. Gray; a claim which Zimmerman (1958) seriously doubted. A number of possible host-plants have been suggested; most grow in close proximity to the Kalalau lookout, Koke'e State Park, Kaua'i, the area where most adults have been found. *Claoxylon sandwicense* Müll. Arg. was formally suggested by Bianchi (1986), *Coprosma* ("pilo") semi-formally by C. Davis (Hawaii Dept. of Agriculture memo, 1971), and *Melicope* ("mokihana") informally by V. Tanimoto (pers. comm.) as possible host plants. This paper documents the first attempt to discover the larval host-plant(s) of *T. smaragditis* by offering foliage to first instar larvae.

MATERIALS AND METHODS

A dead *T. smaragditis* adult female was received on 4 August 1992 from G.K. Kawakami, Hawaii Department of Land and Natural Resources (DLNR). He had collected it 29 July 1992 at rest on *Charpentiera densiflora* Sohmer growing at about 122 m elevation in the Ho'olulu Valley, Na Pali Coast, Kaua'i, Hawai'i. The specimen was contained in a 0.94 l glass jar within which it had laid 58 eggs. The adult was removed from

the jar and pinned. The eggs were not disturbed and held for eclosion. Before and during the eclosion period, plant material was gathered for host-plant testing. Native plants, especially suspected host-plant species, were collected in Koke'e State Park, Kaua'i. Twenty-three plant species, mostly endemic, were collected, including all previously suspected host-plants and a congener of the plant Kusche claimed to have found larvae upon. Included was foliage from *Charpentiera* sp., the genus of tree on which the adult was found. All collected plant material was placed in plastic bags and taken to the entomology laboratory, Plant Industry Facility, Hawaii Department of Agriculture (HDOA), Lihue, Kaua'i. In addition, common plants growing at-large around this same facility and the community were collected and held for host-testing. Arrangements were made with the Hawaii Plant Conservation Center, National Tropical Botanical Garden (NTBG), Lawa'i, Kaua'i, to allow us to conduct larval host-plant feeding tests. The large NTBG collection consisted of many native plants; species not obtained during plant collecting trips to Koke'e State Park. Host-plant testing took place from 7–9 August 1992 and used a combination of the 3 methods described below.

Method 1

A larva was removed from the jar with a fine-tipped brush and placed on foliage of one of the native plant species from Koke'e State Park. The larva was allowed to remain on the foliage for >5 minutes. The recorded data consisted of noting if: 1) feeding was attempted; 2) feeding was performed; or 3) feeding was neither attempted nor performed. This procedure was conducted with each plant species from Koke'e State Park as well as introduced, at-large plant species. For the Koke'e State Park plants, the procedure was repeated a second time, but on a different day. Many different larvae were used throughout these trials to reduce handling stress.

Method 2

Four larvae were placed in a glass petri dish (ca. 9 cm diam.) and held overnight with young leaves of plant species collected at Koke'e State Park. Leaves were examined the following day for evidence of feeding. The design was replicated twice. The trial was conducted twice; different larvae were used. In addition, *Melicope* leaves alone were offered twice using a variation of this method; leaves were placed in the original jar which contained the bulk of the larvae.

Method 3

About a dozen larvae were taken to NTBG where, in each trial, an individual was placed singly with a fine-tipped brush onto a young leaf of a potted, native plant growing under shade cloth. An individual was allowed to remain undisturbed for about 3–4 min; long enough for a starving larva to generally cease walking and begin feeding. Information provided by NTBG on each species' status under the Endangered Species Act or its frequency of occurrence (e.g., rare vs. common) was recorded. As in Method 1, the data recorded were: 1) feeding was attempted; 2) feeding was performed; or 3) feeding was neither attempted nor performed.

Though not host-plant testing, General Purpose Insect Diet® (Product #9002, Bioserv Inc., Frenchtown, New Jersey) was also prepared and small cubes of it were offered to larvae in a petri dish. It was not known to us at the time that some success had been achieved years earlier with the pinto bean diet used by Riotte (1993).

Voucher specimens (adult, unhatched eggs, and some larvae) were deposited at the Hawaii Department of Agriculture office in Lihue.

Table 1. Plant species exposed to *Tinostoma smaragditis* first instar larvae to determine host plant(s).

Family	Species	Source	Common name	Current Status[a]
Aizoaceae	*Tetragonia tetragonioides* (Pall.) Kuntze	At-large	New Zealand spinach	–
Amaranthaceae	*Charpentiera* sp[c]	Kokee S.P.	–	–
	Charpentiera densiflora Sohmer[b]	NTBG	–	rare
	Gomphrena globosa L.	At-large	globe amaranth	–
	Nototrichium sp. nov.[c]	NTBG	–	rare
Apiaceae	*Peucedanum sandwicense* Hillebr[c]	NTBG	–	proposed endangered
Apocyanaceae	*Alyxia oliviformis* Gaud[c]	Kokee S.P.	maile	–
	Pteralyxia kauaiensis Caum[b]	NTBG	–	endangered
Aquifoliaceae	*Ilex anomala* Hook. & Arnott	Kokee S.P.	–	–
Araliaceae	*Cheirodendron* sp[c]	Kokee S.P.	–	–
	Cheirodendron trigynum (Gaud.) A. Heller[c]	NTBG	–	common
	Tetraplasandra waimeae Wawra[b]	NTBG	–	common
Asteraceae	*Ageratum houstonianum* Mill.	At-large	–	–
	Aster gayerii Geyeri (Gray) Howell?	At-large	–	–
	Artemisia australis Less[c]	NTBG	–	common
	Bidens cosmoides (Gray) Sherff[c]	NTBG	–	rare
	Bidens pilosa L.	At-large	–	weed
	Bidens sandvicensis Less[c]	NTBG	–	common
	Bidens sandviciensis confusa Nagata & Ganders[b]	NTBG	–	rare
	Conyza sp.	At-large	–	–
	Dubautia sp.[c]	NTBG	–	rare
	Emilia sp.	At-large	Flora's paintbrush	–
	Gnaphalium sandwicensium var. *molokaiense* Degener & Sherff[c]	NTBG	–	common
	Hesperomannia arbuscula Hillebr.[c]	NTBG	–	endangered
	Remya kauaiensis Hillebr.[b]	NTBG	–	endangered
	Tagates sp.	At-large	marigold	
	Tetramolopium filiforme Sherff var. *filiforme*[c]	NTBG	–	endangered
	Youngia japonica (L.) DC	At-large	Oriental hawkbeard	–
Balsaminaceae	*Impatiens wallerana* Hook	At-large	impatiens	–
Brassicaceae	*Lepidium serra* Mann[b]	NTBG	–	rare
	Brassica oleracea L. var. *capitata* L.	At-large	cabbage (seedlings)	–
	Brassica rapa L. var. *chinensis* L. (Kitamura)	At-large	pak choi	–
Campanulaceae	*Cyanea grimesiana obatae* (St. John) Lammers[c]	NTBG	–	rare
	Cyanea stictophylla Rock[c]	NTBG	–	rare
Caryophyllaceae	*Alsinidendron lychnoides* (Hillerbr.) Sherff[b]	NTBG	–	rare

Table 1. Plant species exposed to *Tinostoma smaragditis* first instar larvae to determine host plant(s) (continued).

Family	Species	Source	Common name	Current Status[a]
Caryophyllaceae	*Alsinidendron obovatum* Sherff[c]	NTBG	–	endangered
	Alsinidendron trinerve Mann[c]	NTBG	–	endangered
	Alsinidendron viscosum (Mann) Sherff[b]	NTBG	–	rare
	Schiedea hookeri Gray (ex. Oahu)[c]	NTBG	–	rare
	Schiedea kaalae Wawra (ex. Oahu)[c]	NTBG	–	rare
	Schiedea verticillata Brown[c]	NTBG	–	endangered
	Silene lanceolata Gray (ex. Oahu)[c]	NTBG	–	endangered
Commelinaceae	*Commelina diffusa* Burm.	At-large	hono hono	–
Convolvulaceae	*Ipomea batatas* (L.) Lam.	At-large	sweet potato	–
	Jacquemontia ovalifolia (Choisy) Hallier	NTBG	–	common
	Jacquemontia ovalifolia sandwicensis (Gray) Robertson	NTBG	–	common
Curcubitaceae	*Mormodica charantia* L. (prob. var. *abbreviata*)	At-large	bitter melon	–
Cyperaceae	*Frimbristylus cymosa* Br.	NTBG	–	common
Ebenaceae	*Diospyros* sp.	NTBG	–	common
	Diospyros sandwicensis (A. DC) Fosb. (ex. Hawaii Island)[c]	NTBG	–	common
Euphorbiaceae	*Clayoxylon sandwicense* Müll. Arg.[c]	Kokee S.P.	–	–
	Flueggea neowawraea Hayden[c]	NTBG	–	rare
Fabaceae	*Arachis hypogaea* L.	At-large	peanut	–
	Erythrina sandwicensis Degener[c]		–	common
	Phaseolus sp.	At-large	string bean	–
	Senna gaudichaudii (Hook. & Arnott) Irwin & Barneby (ex. Oahu)	NTBG	–	common
	Sesbania tomentosa Hook. & Arnott[c]	NTBG	–	common
	Sophora chrysophylla (Salisb.) Seem.[c]	NTBG	–	rare
	Tephrosia purpurea (L.) Pers.	NTBG	–	common
Goodeniaceae	*Scaevola* sp.[c]	Kokee S.P.	naupaka	–
	Scaevola coriacea Nutt. (ex. Maui)[c]	NTBG	–	endangered
	Scaevola gaudichaudii Hook. & Arnott[c]	NTBG	–	common
	Scaevola procera Hillebr.[c]	NTBG, Kokee S.P.	–	common
	Scaevmontia ovalifolia sandwicensis?	NTBG	–	common
Lamiaceae	*Haplostachys haplostachya* (Gray) St. John[c]	NTBG	–	common
	Phyllostegia electra Forbes[b]	NTBG	–	common
	Stenogyne angustifolia Gray[c]	NTBG	–	endangered
	Stenogyne purpurea Mann[b]	NTBG	–	common

Table 1. Plant species exposed to *Tinostoma smaragditis* first instar larvae to determine host plant(s) (continued).

Family	Species	Source	Common name	Current Status[a]
Lamiaceae	*Stenogyne scrophularioides* Benth.[c]	NTBG	–	rare
	Stenogyne campanulata Weller & Sakai[b]	NTBG	–	rare
Liliaceae	*Asparagus officinalis* L.	At-large	asparagus	–
Lythraceae	*Lythrum maritimum* Kunth	NTBG	–	common
Malvaceae	*Abutilon menziessi* Seem.[c]	NTBG	–	endangered
	Gossypium tomentosum Nutt. ex. Seem (ex. Molokai)[c]	NTBG	–	common
	Hibiscadelphus distans Bishop & Herbst[b]	NTBG	–	endangered
	Hibiscadelphus giffardianus Rock[c]	NTBG	–	rare
	Hibiscadelphus hualalaiensis Rock[c]	NTBG	–	status not given
	Hibiscus arnottianus Gray[c]	NTBG	–	common
	Hibiscus arnottianus immaculatus (M. Roe) D. Bates[c]	NTBG	–	endangered
	Hibiscus brackenridgei Gray var. *brackenridgei*[c]	NTBG	–	rare
	Hibiscus brackenridgei mokuleianus (M. Roe) D. Bates[c]	NTBG	–	rare
	Hibiscus clayi Degener & Degener[b]	NTBG	–	proposed endangered
	Hibiscus kokio Hillebr.[c]	NTBG	–	rare
	Hibiscus kokio var. *pukoonis* Caum[c]	NTBG	–	common
	Hibiscus kokio stjohnianus (Roe) Bates[b]	NTBG	–	common
	Hibiscus waimeae hannerae (Degener & Degener) D. Bates[b]	NTBG	–	rare
	Kokia kauaiensis (Rock) Degener & Duvel[b]	NTBG	–	rare
	Kokia drynarioides (Seem.) Lewton[c]	NTBG	–	endangered
	Sida fallax Walp.	NTBG	–	common
Musaceae	*Musa* x paradisiaca L.	At-large	banana (fruit)	–
Myrsinaceae	*Myrsine lanaiensis* Hillebr.[c]	Kokee S.P.	–	–
Myrtaceae	*Metrosideros polymorpha* Gaud.[c]	Kokee S.P.	'ohi'a	common
	Syzygium sandwicensis (Gray) Nied.[c]	Kokee S.P..	–	–
Oleaceae	*Nestegis sandwicensis* (Gray) Degener, I. Degener & L. Johnson[c]	Kokee S.P.	–	–
Passifloraceae	*Passiflora edulis* Sims	At-large	lilikoi	–
Piperaceae	*Peperomia tetraphylla* (Forster) Hook. & Arnott	NTBG, Kokee S.P.	–	common
	Piper methysticum Forster	NTBG	–	–
Pittosporaceae	*Pittosporum napaliense* Sherff[b]	NTBG	–	rare
Plantaginaceae	*Plantago princeps* var. *laxiflora* Gray[c]	NTBG	–	rare
Poaceae	*Cynodon dactylon* (L) Pers. ("Tifton" variety)	At-large	Bermuda grass	–

Table 1. Plant species exposed to *Tinostoma smaragditis* first instar larvae to determine host plant(s) (continued).

Family	Species	Source	Common name	Current Status[a]
Primulaceae	*Lysimachia filifolia* Forbes[c]	NTBG	–	proposed endangered
Rhamnaceae	*Colubrina asiatica* (L.) Brongn.	NTBG	–	common
	Gouania meyenii Steud. (ex. Oahu)[c]	NTBG	–	endangered
	Gouania hillebrandii Oliver[c]	NTBG	–	endangered
Rosaceae	*Fragaria chiloensis* (L.) Duchesne	At-large	strawberry	–
Rubiaceae	*Bobea brevipes* Gray[c]	Kokee S.P.	–	–
	Bobea sandwicensis (Gray) Hillebr.[c]	NTBG	–	common
	Bobea timonioides (Hook) Hillebr.[c]	NTBG	–	rare
	Coffea arabica L.	At-large	coffee	–
	Coprosma ernodeoides Gray (ex. Hawaii Island)[c]	NTBG	–	common
	Coprosma kauensis (Gray) A. Heller[b]	Kokee S.P.	pilo	–
	Coprosma waimeae Wawra[b]	Kokee S.P.	–	–
	Gardenia brighamii Mann (ex. Oahu)[c]	NTBG	–	endangered
	Gardenia remyi Mann[c]	NTBG	–	rare
	Hedyotis acuminata (Cham. & Schlechtend.) Steud.[c]	Kokee S.P.	–	
	Hedyotis littoralis (Hillebr.) Fosb.[c]	NTBG	–	common?
	Hedyotis st.-johnii Stone & Lane[b]	NTBG	–	endangered
	Hedyotis terminalis (Hook. & Arnott) W.L. Wagner & Herbst[c]	Kokee S.P.	–	–
	Morinda citrifolia L.	NTBG	–	common
	Psychotria sp.[c]	Kokee S.P.	–	–
	Psychotria hawaiiensis (Gray) Fosb.[c]	NTBG	–	rare
Rutaceae	*Melicope anisata* (Mann) Hartley & Stone[b]	Kokee S.P.	mokihana	–
	Melicope hawaiensis (Wawra) Hartley & Stone[c]	NTBG	–	common
	Melicope mucronulata (St. John) Hartley & Stone (ex. Molokai)[c]	NTBG	–	endangered
	Melicope ovata (St. John & Hume) Hartley & Stone[b]	Kokee S.P.	–	–
	Zanthoxylum dipetalum var. *tomentosum* Rock[c]	NTBG	–	rare
	Zanthoxylum hawaiiense Hillebr.[c]	NTBG	–	rare
	Zanthoxylum kauaense Gray[c]	Kokee S.P.	–	–
Santalaceae	*Santalum freycinetianum* var. *pyrularium* (Gray) Stemmermann[c]	NTBG	–	common
	Santalum paniculatum var. *pilgeri* (Rock) Stemmermann[c]	NTBG	–	common
Sapindaceae	*Alectryon macrococcus* Radlk. var. *macrococcus*[c]	NTBG	–	endangered
	Dodonaea viscosa Jacq.	NTBG, Kokee	–	common

Table 1. Plant species exposed to *Tinostoma smaragditis* first instar larvae to determine host plant(s) (continued).

Family	Species	Source	Common name	Current Status[a]
Sapindaceae	*Alectryon macrococcus* Radlk. var. *macrococcus*[c]	NTBG	–	endangered
	Dodonaea viscosa Jacq.	NTBG, Kokee	–	common
Sapotaceae	*Pouteria sandwicensis* (Gray) Baehni & Degener[c]	NTBG	–	common
Solanaceae	*Nothocestrum breviflorum* Gray[c]	NTBG	–	rare
	Solanum sandwicense Hook. & Arnott[c]	NTBG	–	proposed endangered
Sterculiaceae	*Waltheria indica* L.	NTBG	–	common
Taccaceae	*Tacca leontopetaloides* (L.) Kuntze	NTBG	arrowroot	-
Thymelaeceae	*Wikstroemia oahuensis* (Gray) Rock[c]	Kokee S.P.	–	–
Urticaceae	*Pilea microphylla* (L.) Liebm.	At-large	pilea	–
	Pipturus sp.[c]	NTBG	mamake	-
	Touchardia latifolia Gaud.[c]	NTBG	–	common
	Urera glabra (Hook.) & Arnott) Wedd.[c]	NTBG	–	common
Violaceae	*Isodendrion hosakae* St. John[c]	NTBG	–	endangered
Zingerberaceae	*Zingiber officinale* Roscoe	At-large	shoga (leaves)	–
	Zingiber zerumbet (L.) Sm.	NTBG	ginger	–

[a] As cataloged by the National Tropical Botanical Garden (Chapin 1993).

[b] Endemic only to Kaua'i according to to Wagner et al. (1990).

[c] Endemic to the Hawaiian islands according to Wagner et al. (1990).

RESULTS AND DISCUSSION

The eggs appeared sound; 7 were pale green and the remainder green with reddish markings. They were about 1.1 mm in length and about 0.9 mm in width. There was no sign of stemmata or mandibles. The first egg hatched before 0730 h on 7 August; the larva consumed the remains of the egg. The first instar larva was about 3 mm long, but after consuming its egg it measured about 4 mm. The larva was pale green overall, except for the prominent caudal horn, which was slightly red in color. A second larva hatched by 0900 h and the third by 0930 h. The remaining fertile eggs continued hatching and, though not closely observed, all probably hatched by the following day. Ultimately, 46 (79%) of the 58 eggs successfully hatched. Of the unsuccessful 12, the 7 green eggs never changed appearance, 4 others showed signs of development or pharate larvae, and the remaining egg hatched, but the larva chewed into another hatched egg before expiring.

We tested 102 plant species endemic to the Hawaiian Islands, of which 22 species were endemic to Kaua'i (Table 1). Through use of the 3 methods, we observed no feeding nor any attempted feeding nor evidence of feeding on tested plants. Thus, the host-plant(s) remain(s) unknown. Likewise, we found no evidence of larvae using the artificial diet. Altogether, 139 species of plants, the majority native, representing 98 genera in 45 families, were tested. Because there are 956 native flowering plants in Hawaii, of which 850 are endemic (Wagner et al. 1990), there remain a substantial number of untested plants, which presumably includes the host. Considering only species endemic to Kaua'i

(the number of which is not summarized by Wagner et al. 1990), the number of untested species is probably quite substantial. However, it is probably not unreasonable to suspect that the host plant(s) is endemic to Kaua'i.

As stated earlier, the larvae began hatching on 7 August 1992 and by the end of 13 August all had died. The only nourishment after eclosion was remnant egg tissue. It is therefore reasonable to assume that larvae were hungry during the host-plant trials and if any plant offered had been marginally suitable, it would have evoked a feeding response. It is possible that factors such as leaf age, micro-environment, handling, or other could negatively influence larval feeding behavior, but given the conditions and brief time available for testing, these and other possible negative factors could not be controlled.

As evidenced by the methods employed, we assumed that larvae were leaf feeders as is typical for sphingids. While it is possible that some other plant part might be fed upon or that they might feed on non-vascular plants, these possibilities were not addressed through testing.

Despite the outcome of the trials, a sizeable amount of useful "negative information" was generated. Tested plant species should be viewed as unlikely host-plants based on these trials. Useful positive information generated were physical and temporal data for the egg and first instar larva of this rare species.

ACKNOWLEDGEMENTS

We gratefully acknowledge the donation of the adult specimen by G. Kawakami to the HDOA collection in Lihue. He also provided plant material and plant identifications. We appreciate the cooperation and assistance of staff members from NTBG, especially T. Flynn for locating *Charpentiera* and identifying plant specimens from Koke'e. D. Jamieson provided additional *Melicope* for testing. J.C.E. Riotte kindly supplied information on his experience with *T. smaragditis* larvae.

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Manuscript submitted: 6 Aug. 1993
Manuscript accepted: 10 Nov. 1993